Comment on the Measurement of Cosmological Birefringence

J. P. Leahy
University of Manchester, NRAL, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, England
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Nodland and Ralston [1] claim evidence for a wavelength-independent cosmic birefringence. Although it has been shown [2] that the data analysed in [1] does not support this conclusion, the possibility of such an effect remains interesting. Here I present a much more accurate test.

It is well known [3] that there is a close relation between the polarization and total intensity structures of the double lobes of radio galaxies and quasars. In particular the projected magnetic field (perpendicular to the Faraday-corrected polarization orientation χ) is predominantly perpendicular to strong gradients in total intensity, in excellent agreement with theory and MHD simulations [3,4]. These qualitative patterns are visible out to $z > 3$ [5]. The complexity of the radio structure guarantees that the integrated χ, an intensity-weighted vector average, is a small residual with only a loose relation to the orientation of the lobes on the sky, ψ (often misdescribed as the major axis of the galaxy). Unfortunately [1] and others use $\chi - \psi$ as an indicator of the birefringent rotation β, which inevitably introduces a great deal of noise into any relation with other quantities.

Consider instead the detailed agreement available at high resolution, for instance Fig. 1. Using the well-established trend noted above, we can determine β accurately by comparing the local χ values with the local direction of the intensity gradient, ϕ. A clear peak in the $\chi - \phi$ histogram is apparent at $-2° \pm 2°$, consistent with zero cosmic birefringence. A major contribution to the peak comes from the edges of the lobes, where alignment is excellent in most sources. Table I lists similar results for all those radio sources with $z > 0.3$ for which suitable digital images were to hand, together with 3C 9, in which the alignment between polarization and jet direction has been studied quantitatively [6]. Here β(pred) gives the predicted rotation according to the fit of [1], while β(obs) gives the observed rotation based on the mode of the $\chi - \phi$ histogram for each object. For sources from [7] and [8], χ has been fully Faraday-corrected; for the others, I use images at $\lambda 3.6$ cm, corrected for integrated Faraday rotation; differential effects are at most a few degrees. In no case is a significant β(obs) detected; any dipole along the axis found in [1] must be $\lesssim 3\%$ of the claimed amplitude.

I thank J. Ralston for constructive criticism.

[1] B. Nodland and J. P. Ralston, Phys. Rev. Lett. **78**, 3043 (1997).
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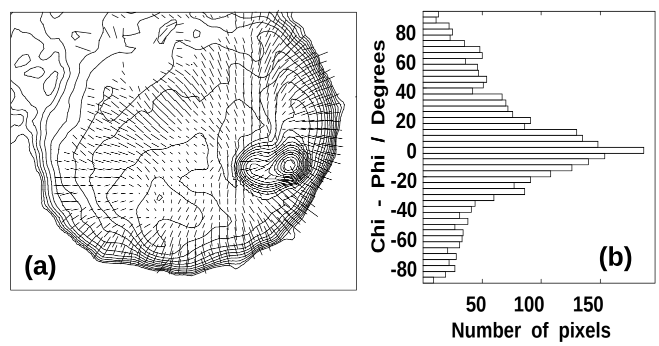

FIG. 1. (a) Contours of total intensity for the south lobe of the quasar 3C 47, with line segments showing χ. (Faraday rotation in the north lobe is too large to correct). (b) Histogram of $\chi - \phi$, at all points where $\sigma_{\chi-\phi} < 15°$.

TABLE I. Data on selected radio sources.

Name	redshift, z	β(pred)	β(obs)	ref.
3C 9	2.012	125°	2° ± 3°	[6]
3C 34	0.6897	54°	8° ±12°	[8]
3C 47 S	0.425	35°	−2° ± 2°	[7]
3C 55	0.735	34°	6° ± 9°	[9]
3C 228	0.5524	−113°	−13° ±20°	[8]
3C 244.1	0.428	−49°	−1° ± 9°	[9]
3C 265	0.8108	−94°	0° ±10°	[9]
3C 268.1	0.97	−32°	13° ±20°	[9]
3C 330	0.428	14°	−5° ±12°	[9]
3C 340	0.7754	49°	−6° ± 9°	[8]

Reply to astro-ph/9706126

Nodland & Ralston's response [1] to my comment [2] on their paper [3] points out an error (now corrected in the revised submission), which does not affect my conclusion. They also accuses me, falsely, of selecting unrepresentative data, and put forward a number of other criticisms, none of which are valid.

As noted by [1], I do not address their correlation in [2]. Instead I address their conclusion, that there is cosmic birefringence, which was a major feature of their title, abstract, text, and media publicity. I believe that [4] have already disposed of the correlation, notwithstanding the counter-arguments presented in [5] and [1].

My comment, centrally, presents an operationally *different* measure of birefringence from that used by [3]; one which is much more accurate that the original. Because the scatter in my measure is so small, data on only a few representative objects gives a much clearer result than statistical analysis of the large database used by [3]. My measure has a clean observational and theoretical grounding (despite the misinformed criticisms in [1], discussed below), so that any rotation detected would almost certainly be a propagation effect. Conversely and obviously, any propagation effect that affects the measure used by [3] would also show up in my measure. The two would only be incompatible if, as proposed by [6], the original measure was affected by an anisotropy in the *source* distribution, in which case the genuine test of birefringence would be my measure.

I have slightly changed the notation in the revised version of [2] to minimise confusion. However, I retain the use of the symbol β to denote the angle by which the plane of polarization is rotated due to cosmic birefringence, following Eq. (1) of [3]. On this definition β is intrinsically a scalar variable, although any observational estimator is subject to $n\pi$ ambiguity. Eqs. (2) of [3] resolve this by arbitrary *fiat* which frequently disagrees with the $n = 0$ required to make sense of the data (see below), and I therefore avoid this approach. In passing, I note that there is no sign ambiguity; counterclockwise rotation (looking along the ray) is positive, as standard in astronomy (the value of β(obs) for 3C 47 was originally quoted unsigned in the text of [2]; this has now been changed).

I am grateful to Nodland & Ralston [1] for pointing out that my calculation of β from their formula was wrong (due to a programming error). I have revised these values and believe that they are now correct.[1]. The changed values of β(pred) do not affect the limit I can place on any birefringence.

The principle objection raised by [1] is that the narrow dispersion around zero of the β(obs) values listed in Table 1 of [2] is due to my selection of a few special cases (or even special parts of special cases), and to my neglect of a large body of data that would have given a different result. This is simply a fantasy. Given that the numbers in the Table are representative, the other objections raised in [1] collapse.

The selection of sources, as stated in [2], was determined by availability of (digital) data to me (except for 3C 9); this was because a fresh analysis of the images was required to derive the gradient angles and difference them from the polarization angles. These images were obtained for a variety of purposes, unrelated to the current topic. I excluded objects at $z < 0.3$ since they have little predicted rotation according to [3]. I also originally excluded three unpublished objects at moderate redshift with low β(pred). Due to the error in my program, two of these should have been included; given the suspicions in [1], I have included all three in the revised version. I have access to no data on any other objects at $z > 0.3$ suitable for this analysis (the requirements for "suitability" are given below). I have re-phrased the text of [2] to explicitly state this lack of bias.

I did not, of course, select parts of sources because they "look pretty". As clearly implied in [2], I used histograms of $\chi - \phi$ for each object using every point with good signal-to-noise and for which Faraday rotation could be either accurately determined or reasonably neglected, as described below.

Fig. 1a of [2] shows a restricted region of 3C 47 (actually most of southern lobe) because this allows a sufficiently large scale for the polarization pattern and its relation to the total intensity structure to be clearly visible, and because the data in the rest of the source does not meet the criteria noted above. In particular, as illustrated in [7], the Northern lobe is heavily depolarized at 18 cm, implying high Faraday depths which makes accurate determination of Faraday rotation with this data impossible. 3C 47 is the only case where a substantial fraction of the object is obscured by the Faraday effect.

All the histograms follow the general pattern of Fig. 1b of [2], i.e. they show that, while all values of $\chi - \phi$ occur, there is clearly a preferred value, which is close to zero as expected from the alignment effect. Thus Fig. 1 of [2] does show undetectably low birefringent rotation in the direction of 3C 47; Table 1 establishes that negligible birefringence occurs in a variety of directions spread around the northern sky.

If it were granted that the objects I listed were not maliciously or incompetently selected, my data alone would establish the alignment trend illustrated in Fig. 1 of [2], since one requires both a low birefringence and a consistent intrinsic alignment to obtain a small scatter of β(obs) around zero. However, the trend is also well doc-

[1] Pace [1], $\cos(\gamma)$ for 3C 47 is definitely positive, using either of the poles determined by [3] and irrespective of whether the equinox of these poles is 1950 or 2000. For the values in Table 1, I used the first pole and assume equinox 1950, as this was used for the source positions in the references cited by [3].

umented in the authoritative reviews I cited [8].

The data quality requirements for images which clearly show the polarization structure are strict: Firstly, the data must be good enough that accurate polarization angles are determined in $\gtrsim$50 independent positions, to ensure that at least the overall structure of the the field is resolved. Secondly, Faraday rotation should be corrected, ideally at each pixel using images at several wavelengths to extrapolate the angles to zero wavelength. The extensive data required for this is rarely available. Alternatively, we can apply an integrated correction (usually from published single-dish results), providing that the differential Faraday rotation is small at the wavelength of observation. The latter can be checked, as large differential rotation causes depolarization of the integrated emission, which is also noted in the single-dish publications. In practice this usually means that images with $\lambda \lesssim 6$ cm are required. This correction has been applied to all the $\lambda 3.6$ cm β(obs) values in the revised version as it makes a noticable difference (7°) for the case of 3C 55. Changes to the values reported in the original are at most 2°(for 3C 9).

Contrary to the reference in [1] to "hundreds of examples not looking like this...", I'd be surprised if there are more than about a hundred published cases meeting the above requirements, nearly all being at low redshift, and the vast majority[2] following the alignment trend. I note that [1] do not cite any specific counter-examples, although a few surely exist.

Thus on purely observational grounds there is a high probability that the mode of each $\chi - \phi$ histogram is close to the value of β ($\pm n\pi$). Since in all seven (now ten) cases the mode is close to zero, assigning a value of n other than zero (as would result in some cases from Eqs. 2 of [3]) would imply a cosmic conspiracy, in which large-angle birefringent rotations always occurs in undetectable units of $\approx \pi$.

The dismissal of well-established observational evidence in [1] is paralleled by the dismissal of the widely accepted theoretical interpretation [8] as circular reasoning. Fortunately, we are no longer in the know-nothing phase of 35 years ago, when polarization was first detected. The current "beam model" is not merely consistent with the observations; it has had several substantial successes in explaining, without modification, new observations quite different in kind from the gross total intensity images that inspired it. One of these is its success in accounting for polarization structure: as noted in the papers I cited [9], practically any magnetic configuration assumed for the initial beam generates projected field patterns which qualitatively resemble the observations; in fully 3-D simulations, the agreement becomes quantitative.

[2] A partial exception is the case of jets in FR I sources, in which the polarization often parallels the contours; but these are quite distinct in total intensity structure from the FR II sources analysed here.

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